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IMPACT OF CLIMATE CHANGE ON FLASH FLOODS USING HYDROLOGICAL MODELLING AND GIS: CASE STUDY ZARQA MA'IN AREA

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ABSTRACT

Jordan is located in an arid zone that is subject to flash flood hazard initiated by heavy rainfall storms that frequently prompt massive damage to life and infrastructure. The Zarqa Ma'in catchment area is located in the central part of Jordan, East of the Dead Sea and about 10 km southwest of Madaba city. A major flash flood event occurred in the Zarqa Ma'in area on October 25th, 2018. This event was characterized by a rainfall precipitation amount of 43 mm within 22 minutes. The impact of this flood has been disastrous, with 21 people killed and several injured. This study deals with the analysis of the various factors that caused this flash flood as well as calculation of runoff values for Zarqa Ma'in catchment area through the use of the hydrologic modeling Soil Conservation Services (SCS) method, A method that is often used by hydrologists in arid regions and Watershed Modeling System model (WMS 11) and Geographic Information System (GIS 10.7).

Rainfall and climatological data analysis and interpretation by using frequency analysis indicated an increase in rainfall amounts and temperature during the last 40 years due to global climate change. Analysis of morphometric parameters showed that the morphometric characteristics of the watershed contribute to high-speed floods with low infiltration rates. LU/LC results showed that the bare rocks and soil cover about 35% of the Zarqa Ma'in catchment area which will increase the velocity of runoff water and accelerate its flood peak. In the hydrological modeling, the HEC-HMS model was applied to Zarqa Ma'in watershed to predict the surface runoff after passing with WMS. The peak discharges obtained for the thunderstorm which occurred on October 25th, 2018. The flood hydrograph volume is about 2.98 MCM with a peak discharge of about 102.94 m^3/s for sub-basin 1, 1.31 MCM with a peak discharge of about 126.66 m^3/s for sub-basin 2 and 4.3 MCM with a peak discharge of 146.7 m^3/s at the outlet of Zarqa Ma'in catchment. The result of the cross section of sub- basin 1 indicate a water depth of 11m from the ground, while the water depth in the cross-section of sub-basin2 from the ground was 3m.

KEYWORDS: *Zarqa Ma'in, Flash Flood, Curve Number, Morphometric Parameters, Unit Hydrograph*

Article History

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INTRODUCTION

Jordan is classified climatically as an arid region according to the "world map of K€oppen_Geiger climate classification" (Peel et al., 2007). These climates tend to be hot, characterized by rainfall decrement and frequent summer heat waves.

These conditions are immediate consequences of worldwide climatic changes that have recently been influencing several locations in the world (Abdallah, 2020). Climate change, as defined by the United Nations Intergovernmental Panel on Climate Change (IPCC) in the Third Assessment Report (TAR) of working group I, means "any change in climate over time, whether due to natural variability or as a result of human activities." (IPCC, 2017). The IPCC report highlights several climate changes impacts that could be evaded by limiting global warming to 1.5ºC compared to 2ºC, or more unstable weather conditions, which Jordan encounters during the change between seasons, usually bring heavy precipitation that result in flash floods (IPCC, 2017). Many factors are relevant to the occurrence of a flash flood and are divided into meteorological factors and hydrological factors (Youssef et al., 2015). Geomorphology controls the disparities in the elevation, slope degree and slope aspect of the land surfaces and partially, urbanization that causes variations in wind, temperature, precipitation, and cloudiness. Therefore, the differences in the geomorphological configurations cause climatic differences (Keliler et al.,2010). Flash floods are among the most frequent natural disasters in terms of human and economic loss in many countries (Svetlana et al., 2015). Several flash floods were recorded recently in Jordan such as Zarqa Ma'in area, Petra, Downtown Amman, Wadi Al-Waleh, Muleih area and were responsible for dozens of deaths (Al-Sharaan, 2018). On October 25th, 2018 only 22 minutes of rain formed killer flashfloods which swept 21 people, including 16 schoolchildren, to their death in the Zarqa Ma'in Valley in the Dead Sea area (Namrouqa, 2018). After two weeks, on 10 November 2018, another flash flood struck several areas including the popular tourist spot of Petra and another 12 tourists died in South Jordan. Thousands of tourists were forced to leave Petra (Zeineh, 2018). This study on the flash flood of Zarqa Ma'in area will help to evaluate and understand the past flood events and present trends and possibly predicting the future. It will also be helpful in understanding the flood hydrology and geomorphic effectiveness of floods and for planning, management, and administration of flash floods that may happen in future. In addition, this study can assist researchers and decision makers to get an idea about flood cycle of Wadi Zarqa Ma'in i.e. the recurrence interval of floods as well as the area which is under level zone. Moreover, knowledge about the causes and consequences of floods caused by climate change and determining which factors caused the flash flood events will assist in presenting the best mitigation procedures for solving such type of flood problems. Lababneh et. al (2019) conducted a study about hydrological modeling for Al Hasa catchment area using GIS Technique; they used three methods for flood calculations, namely: time of concentration, unit hydrograph, and SCS curve number methods. They concluded that results of the three methods were close and acceptable, however, time of concentration method have the highest value because it takes all ideal variables considered and ignored external variables effects. Al-Weshah and El-Khoury (1999) described a flood analysis model developed and calibrated for the Petra catchment; using this model, flood volumes and flows have been estimated for storm events of different return periods. Farhan and Anbar (2016) conducted a study to assess the flash flood in Wadi Yutum watershed, southern Jordan. The assessment was conducted using remote sensing and geographical information systems (GIS) techniques combined with geomorphic and geological field data to test the probability of flooding risk spatially. Farhan and Ayed (2017) presented a flash flood assessment for Wadi Wuheida (Southern Jordan) and Wadi Rajil (Northern Jordan) watersheds using GIS, DEM, ASTER, and geomorphic field observation. A total of 23 morphometric parameters of paramount importance to flash flood risk estimation were extracted and computed using SRTM DEM, GIS, and mathematical formulae developed for this purpose. Study area. Zarqa Ma'in area is located in the central part of Jordan to the east of the Dead Sea and 10 km south-southwest of Madaba city (Fig. 1). The area of the catchment is around 276 km2 and contains a confined river of about 23 km length. It is characterized by a sub-dendritic drainage network with two main trends, N–S and E–W (Odeh et. al, 2013).

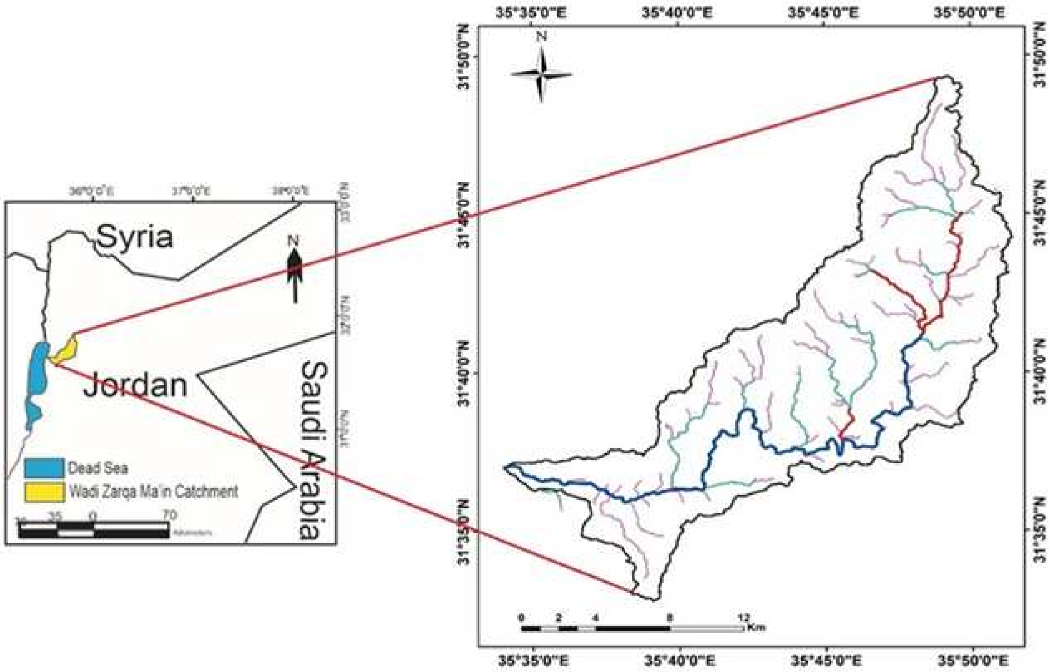

Figure 1: Location of Wadi Zarqa Ma'in.

Zarqa Ma'in area is characterized by moderate to high relief with elevations from -418 m below sea level and 923 m above sea level. Due to the high relief for the study area especially in the south western part the risk of damage caused by a flash flood is very high. Zarqa Ma'in area is very rugged with steep slopes devoid of any soil cover. The soil erosion and runoff velocity are in directly proportional to the degree of slope. Digital Elevation Model (DEM) sourced from Shuttle Radar Topographic Mission (SRTM) with 12.5 m X12.5 m was used to generate different morphometric parameters like slope which present in Figure 2. The Zarqa Ma'in thermal springs are viewed as the main geothermal manifestations in Jordan because of their flow rates and high temperatures. About 100 thermal springs, with temperatures up to 63°C, issue from Lower Cretaceous Sandstone and older units (Sawarieh and Massarweh, 1995). The physical characteristics (climate, soil, geology, land use and vegetation) of the catchment affect indirectly the volume of the flood that forms in it. The average annual precipitation is around 243 mm in Ma'in station. Most precipitation is concentrated between October and April. There are two aquifers in the study area an upper unconfined aquifer and a lower confined aquifer. The upper aquifer is comprised mainly of late Cretaceous and Cenozoic limestone. The lower aquifer consists of early Cretaceous and PermoTriassic sandstones and it has thermal water (up to 58ºC) (Shawabekeh, 1998; Margane et. al, 2002).

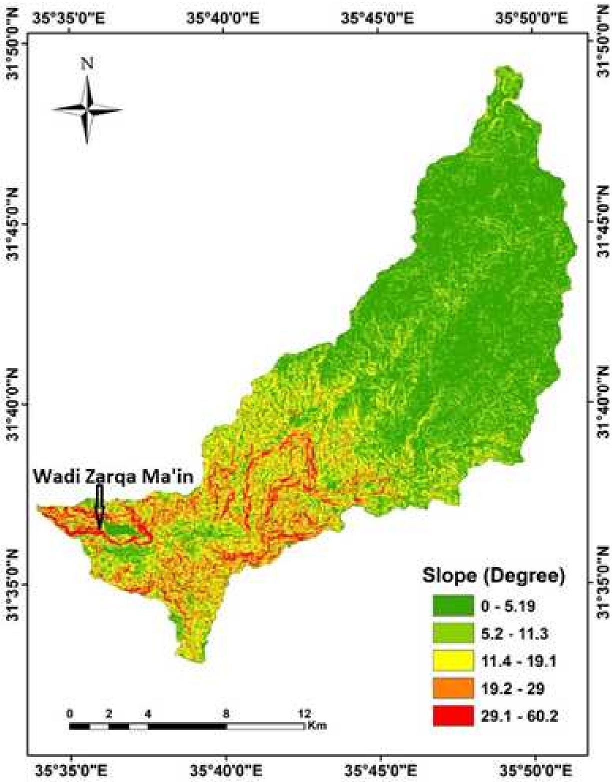

Figure 2: Slope of Zarqa Ma'in Catchment.

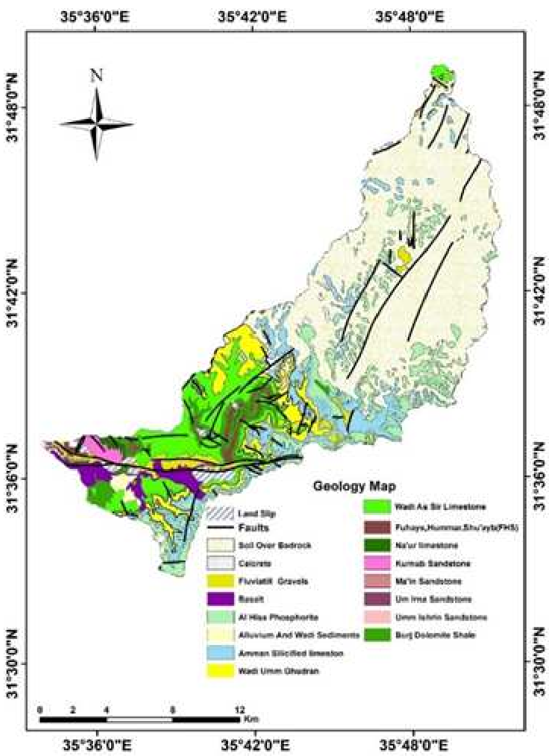

Figure 3: Geological map of Zarqa Ma'in Catchment (Modified After Shawabekeh, 1998).

The rocks in the study area are mostly sedimentary rocks and belong to Paleozoic, Mesozoic, and Cenozoic ages (Shawabekeh, 1998) (Fig. 3). The upper part is consisted mainly of marls, dolomite, and limestone of Upper Cretaceous age with a total thickness of about 700m. The lower part comprises predominantly of semi consolidated sandstones with thin intercalations of marls and limestone with a total thickness of about 650m, ranges in age from Middle Cambrian to Lower Cretaceous (Bender, 1974). The Cenozoic rocks consist of extrusive igneous rocks and clastic and nonclastic sedimentary rocks.

METHODOLOGY

The physically based conceptual approach with available data, which provides more insight into the physical nature of the watershed (landuse and topography) and meteorological (rainfall and runoff), has been adopted. Figure 4 is a flow chart of the methodology used in the current study with its different data sources and data-sets. The Satellite imagery was used for mapping of land use and morphological characteristics. The geological data used in the current study will help in understanding different rock units and map the different soil units. The hydrological data include the historical records of the rainfall dataset will be used for rainfall analysis and statistical distributions, moreover, evaporation, climatological data such as (temperature, relative humidity, wind speed) will be taken into consideration for flood calculations. The hydrological data set was collected from the Ministry of Water and Irrigation (MWI) and Jordan Meteorological Department (JMD). The original dataset has been filtered and tested for its consistency for the last 38 years to be used in this study.

No direct runoff measurements or records are available at the MWI for the catchment area therefore, all hydrological data has been used for estimating the hyetographs for various return periods and runoff volumes during the last 38 years. Runoff volumes were calculated based on three different methods: Curve number (Rainfall-Runoff model approach), Time of Concentration, and Unit hydrograph method. The flood calculations for the catchment area were based on three sets of highly detailed information grouped into three categories: hydrologic, hydraulic, and topographic. The first step is to build the intensity curve–duration–frequency (IDF), and then estimates the peak discharges (Q_{max}) using a statistical method for different average recurrence interval.

The second step, defining basin delineation, stream network, topography, and geometric characteristics by DEM processing, using ARC GIS and WMS model (Myronidis et al., 2016). The third step, modeling rainfall/runoff relation, using HEC-HMS model. Digital elevation model (DEM) from Shuttle Radar Topographic Mission (SRTM) with 12.5x12.5 m spatial resolution was used for extracting the drainage catchments, drainage networks, and morphometric parameters. The fourth step is building the basin model and extracting the cross sections from the DEM along the reach and importing them into the hydraulic model HEC-RAS. The fifth step is creating a conceptual model and defining the network schematic on HECRAS using Manning's roughness coefficient (n) for every cross-sectional area. The sixth step is applying a steady gradually varied flow analysis which consists of peak discharge information, boundary conditions, and flow regime to compute water surface elevation along the channel geometry of wadi Zarqa Main with the return periods of 2, 5, 10, 50, 100, and 1000 years.

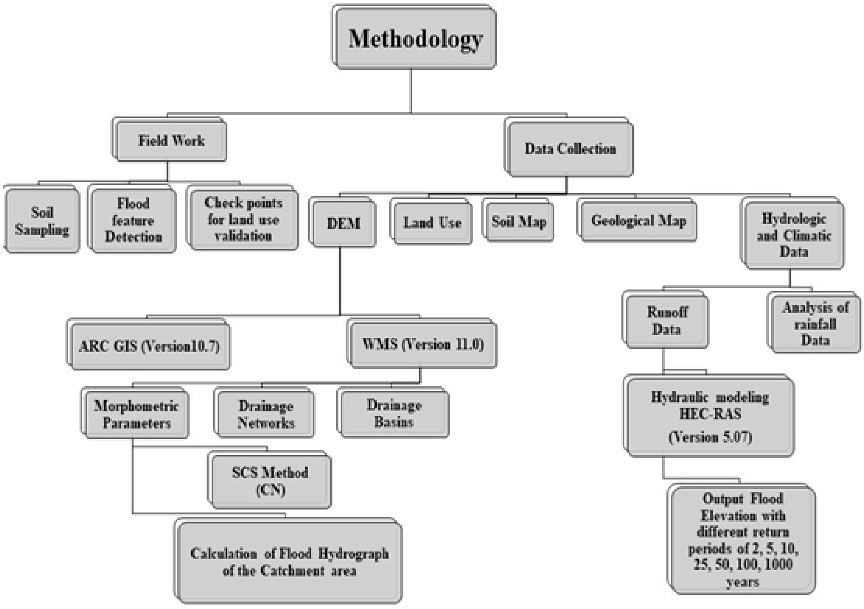

Figure 4: Flow-Chart Summarizing the Methodology.

LAND USE ANALYSIS

An aerial photo was taken and ground-truthing has been conducted to investigate the actual ground cover and take a checkpoint. The google map (2020) was used to construct the land use map of the Zarqa Ma'in catchment and it was classified into nine classes (Figure 5). Table 1 shows these classes, their areas, and their percentages. The bare rocks cover about 16% and the bare soil cover about 19% of the Zarqa Ma'in catchment area which will increase the velocity of runoff water and accelerate its flood peak. This can be inferred from the spread of sandy lands and sedimentary valleys in the lower parts of the watershed, as for agricultural lands, they are widespread which make up about 43% of the catchment area.

Table 1: Total Land use Cover of the Zarqa Ma'in Catchment

Name	Area (Km^2)	Area%
Urban Fabric	10.77	3.90
Tree Crops	19.13	6.93
Water Bodies	0.01	0.003
Bare Soil	18.85	6.83
Bare Rock	45.00	16.30
Wadi Deposits	26.32	9.53
Pastures	35.66	12.91
Field Crops	120.27	43.58
Total	276	100

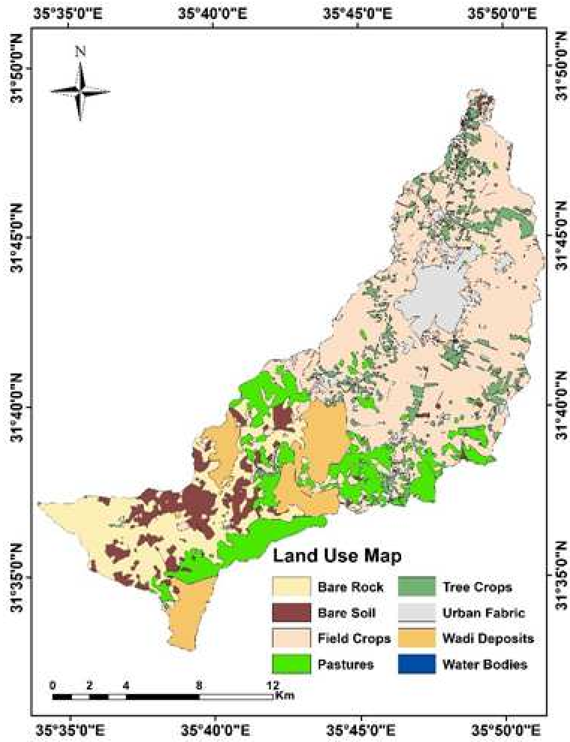

Figure 5: The Land use Map of Zarqa Ma'in Catchment.

SOIL TYPE ANALYSIS

There are eleven types of soil in Zarqa Ma'in basin according to the classification of Ministry of Agriculture in Jordan (1993) (HTS and SSLRC, 1993) as presented in Figure 6. These soil types were reclassified according to their texture in order to be used and reclassified for SCS curve number method. Moreover, 20 representative samples from the study area were collected and analyzed for their texture by hydrometer method. All samples have been classified as of sandy loam, sandy clay loam. This soil is characterized by the amount of water flow. Each type of soil was assigned to its hydrological soil group created by US Soil Conservation Service (SCS) depending on their permeability and infiltration which are divided into 4 groups A, B, C, and D. The soil map was then reclassified into Hydrological Soil Groups (HSG) as shown in Figure 7.

CLIMATE CONDITIONS

Meteorological data for the study area are obtained from two weather stations installed inside and outside the study area. These are Mushaqqar (CC0004) and Wadi Wala (CD0006). Both climatic stations are operated by the Ministry of Water and Irrigation (MWI). Climatic data contain average yearly and monthly values for minimum and maximum temperature, relative humidity, average wind speed, and pan evaporation. The average annual temperature for both stations is 16.3^{o}C and 19.4^{o}C respectively, while the mean temperatures vary from 8 ^{o}C in January to 24^{o}C in July for Mushaqqar station and from 10 ^{o}C in January to 28 ^{o}C in July for Wadi Wala station. It can be seen from Figure 8 that the mean monthly temperature in Wadi Wala station is higher than that in Mushaqqar station in the winter season.

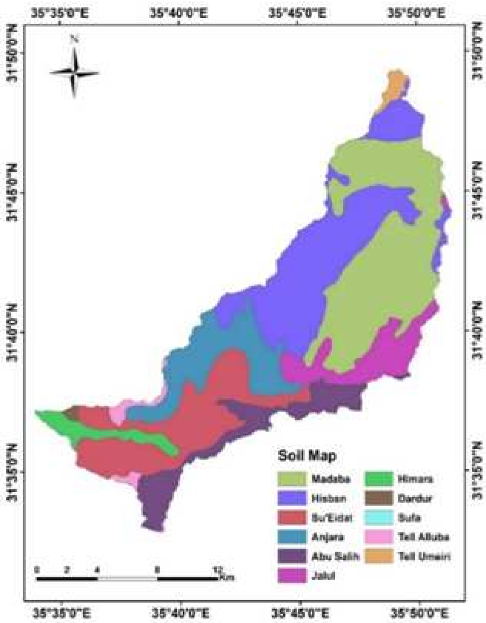

Figure 6: Soil Types of the Zarqa Ma'in Catchment Area (HTS and SSLRC, 1993).

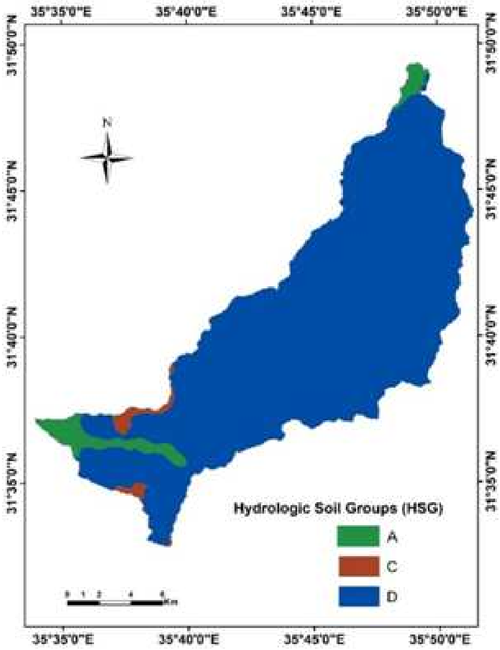

Figure 7: Hydrologic Soil Group in the Zarqa Ma'in Catchment Area.

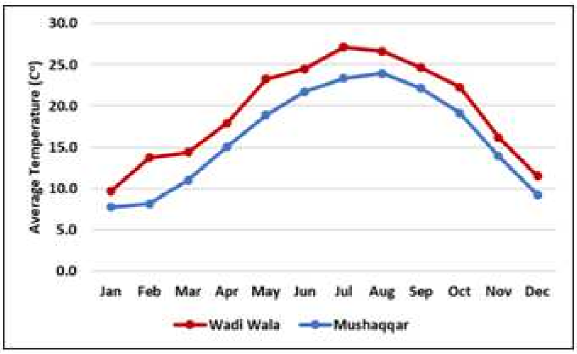

Figure 8: Average Monthly Temperatures in Wadi Wala and Mushaqqar.

The average annual relative humidity of the southern part (Wadi Wala) area is 68.2 %, and it is 62.5 % in the northern part (Mushaqqar) of the catchment area (Fig. 9). Dominant winds in the area , that are from west to north- west, prevail in winter seasons and east, north-east prevail in the summer season. The average potential annual evaporation measured at Mushaqqar station is about 2274.5 mm/year and 2275.5 mm/year in Wadi Wala station. Daily rainfall data from eight rainfall gauging stations inside and outside the Zarqa Ma'in watershed was collected for the last 38 years. These stations are operated by the Ministry of Water and Irrigation (MWI). Locations of these meteorological stations are shown in Figure 10. The highest average annual rainfall was registered at Mushaqqar station inside the catchment area, where the lowest average annual rainfall was at South Shuna station outside of the catchment area (Table 2). The Isohyetal map shows that rainfall varies between 180 mm in the southern part of the catchment to more than 330mm in the northern part (Fig.11).

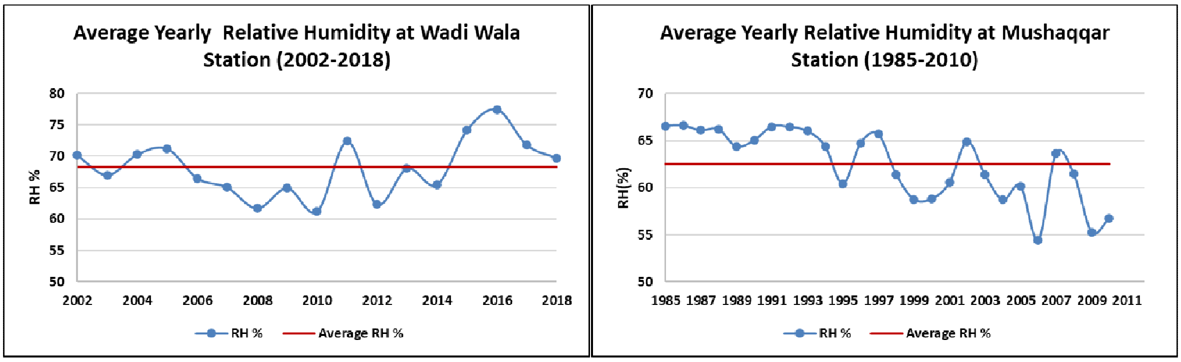

Figure 9: (a) Average Annual Relative Humidity for the Southern Part, and (b) Northern Part of the Catchment Area.

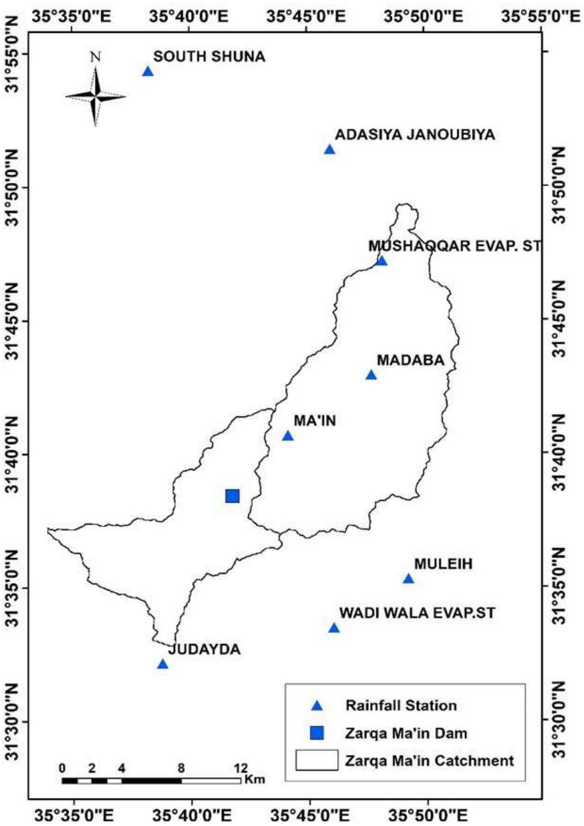

Figure 10: Zarqa Ma'in Catchment and Gauging Stations.

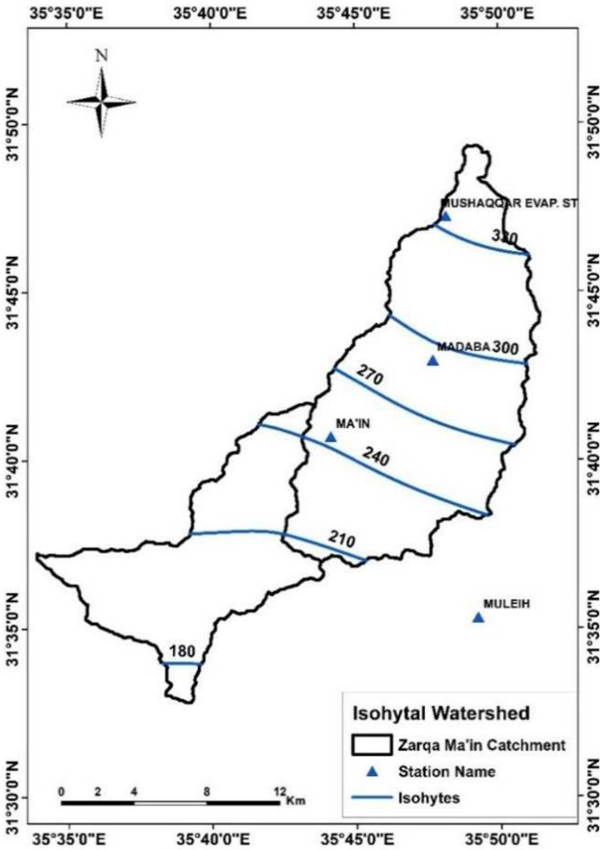

Figure 11: Isohyetal Map for the Zarqa Ma'in Catchment.

Table 2: Average Annual Rainfall in (mm) for the Rainfall Stations

Station ID	Station Name	Start	End	No. of Years	Average Yearly Rainfall (mm)
CC0002	MA'IN	1980	2018	38	243.88
CC0001	MADABA	1980	2018	38	294.7
CD0028	MULEIH	1980	2018	38	205.4
AM0007	SOUTH SHUNA	1980	2018	38	163.1
AN0004	ADASIYA JANOUBIYA	1983	2018	32	295.3
CC0004	MUSHAQQAR EVAP. ST	1985	2018	33	333.4
CD0006	WADI-WALA EVAP.ST	1980	2018	38	254.8
CD0016	JUDAYDA	1981	2018	35	223.18

During the last 38 years, the biggest rainstorms that occurred at Ma'in and Madaba stations (1980-2018) (Fig. 12). It is clear that increasing trend in the maximum daily precipitation over the catchment area during the last ten years which could be attributed to climate change (Abdallah, 2020). According to the records of the rainfall stations found in the Zarqa Ma'in watershed, the annual average rainfall id 243.88 mm in Ma'in station, and 294.68 mm in Madaba station. The annual rainfall data for these stations have been are plotted against the corresponding water year as can be seen in Figure 13.

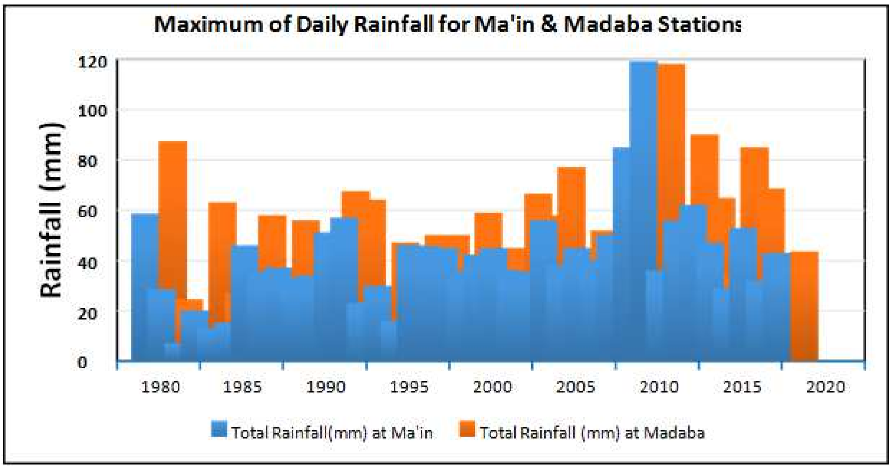

Figure 12: The Highest Rainstorms that Occurred at Ma'in Station and Madaba Stations (1980-2018).

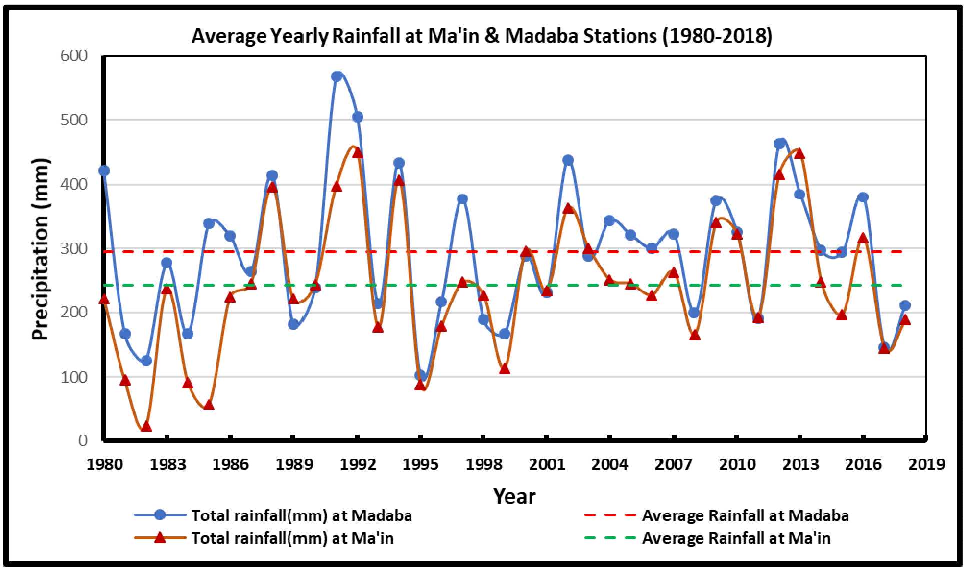

Figure 13: Yearly Rainfall of Ma'in and Madaba Stations.

CATCHMENT CHARACTERISTICS

The morphometric parameters showed that the catchment area has an area of 276 Km^2. The area has been divided into two sub-catchments; both have an elongated shape which contributes to huge amounts of transmission losses. The upper part of the watershed is a pre-dam area and has an area of about 194.79km^2. The lower part has an area of about 81.08 km^2 which is supplied from more than 40 side valleys at a distance of about 25 km to the Dead Sea after the dam, including the Ma'in baths area and other side valleys (Fig. 14). The average overland slope shows the plateaues natural features to low-level features of the study area which speeds overland flow over little distances (449.6 m to 392 m). The Mean basin elevation from the most upstream edge to the outlet differs from 464.8m to 760.6m. The main average slope of the main channel varies from 0.0132 to 0.0566 m/m. The high slope of the main channel indicates the features of the rocks of the study area which promotes to high-speed flash floods. Table 3 shows the morphometric parameters determined in the two sub-basins.

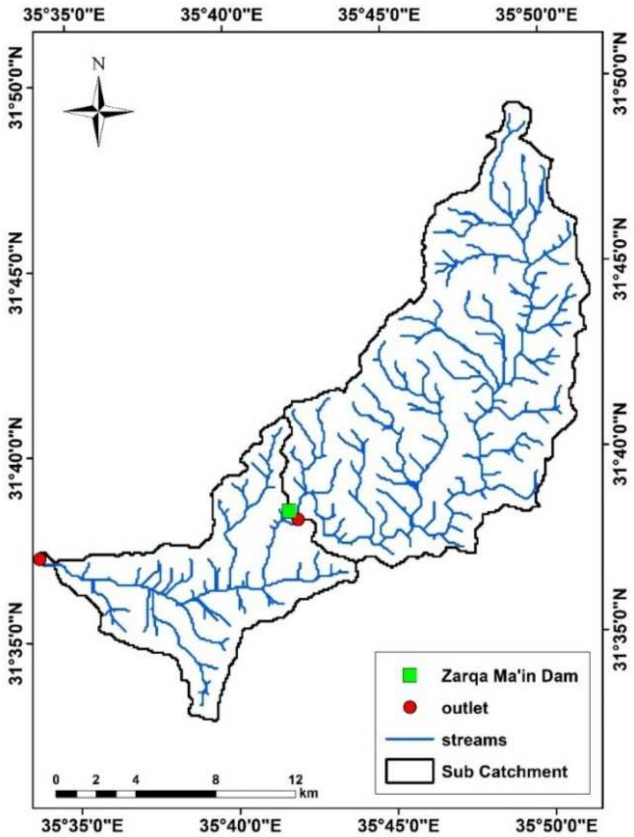

Figure 14: Catchment Area of Zarqa Ma'in and Hydrological Characteristics of the Sub-Basin.

Table 3: The Morphometric Parameters of the Selected Basins in the Catchment Area

Acronym	Description	Sub-Basin (1)	Sub-Basin (2)
AVEL	Mean basin elevation	760.64m	464.82m
AOFD	Average overland flow distance	391.97m	449.66m
BS.	Basin (overland) slope	0.0619m/m	0.2333m/m
MFD	Basin length along main channel from outlet to upstream boundary	39301.22m	2144.2.23m
MFS	Basin slope along main channel from outlet to upstream boundary	0.0132m/m	0.0566m/m
CSD	Length along main channel from outlet to point opposite centroid	24131.6m	10826.27m
CSS	Slope along main channel from outlet to point opposite centroid	0.015m/m	0.0684m/m
MSL	Maximum flow (watercourse) length	38504.09m	20774.86m
MSS	Maximum flow (watercourse) average slope	0.0125m/m	0.0555m/m
L	Basin length	23499.71m	15942.48m
P	Basin Perimeter	89150.25m	69296.24m
CTOSTR	Distance from Centroid to stream	0m	92.03m
Shape	Shape factor	$2.84m^2/m^2$	$3.13m^2/m^2$
CN	Curve Number	91.4	96.2
Area	Basin Area	$194.79Km^2$	$81.08Km^2$

RESULTS AND DISCUSSION

RAINFALL AND RUNOFF ANALYSIS

The rainfall data was utilized to predict the rainfall depth at various return periods. Intensity Duration-Frequency curves used in hydrology for flood forecasting. IDF curves are a classic method of synthesizing results on estimates of precipitation return levels over a range of durations. The daily maximum records of Rainfall stations that were gathered over 38 years and the Intensity-Duration-Frequency (IDF) curves were created utilizing data covering the period of (1980-

2018). All IDF calculations and IDF-curves prepared for all rainfall gauge stations and Table 4 and Figure 15 is an example for Ma'in station.

Table 4: Rainfall Intensity (mm/hr), Duration and Frequency at Ma'in Station

Return Period	Duration (min)									
Year	5	10	20	30	60	120	180	360	720	1440
I2	69.9	44.0	27.7	21.2	13.3	8.4	6.4	4.0	2.5	1.6
I5	101.5	63.9	40.3	30.7	19.4	12.2	9.3	5.9	3.7	2.3
I10	122.5	77.1	48.6	37.1	23.4	14.7	11.2	7.1	4.5	2.8
I25	148.9	93.8	59.1	45.1	28.4	17.9	13.7	8.6	5.4	3.4
I50	168.6	106.2	66.9	51.1	32.2	20.3	15.5	9.7	6.1	3.9
I100	188.1	118.5	74.6	57.0	35.9	22.6	17.2	10.9	6.8	4.3
I1000	252.5	159.1	100.2	76.5	48.2	30.3	23.2	14.6	9.2	5.8

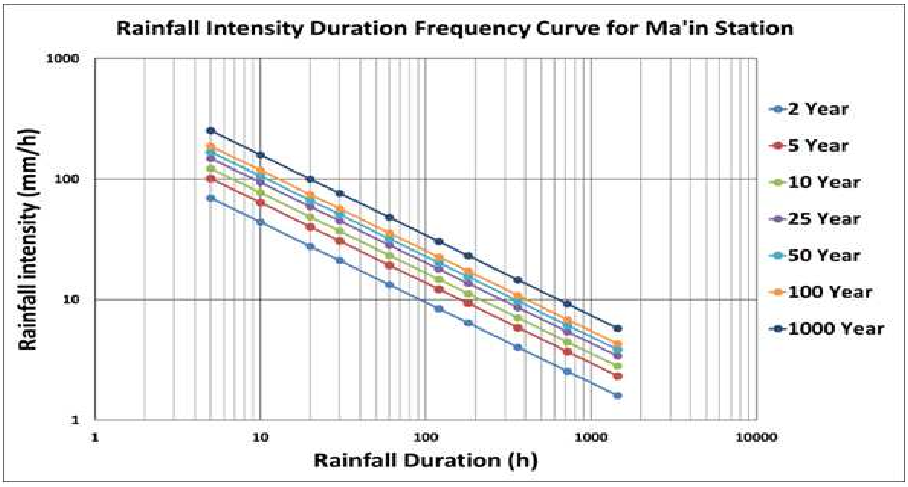

Figure 15: Intensity-Duration-Frequency (IDF) Curve for Ma'in Rainfall Station.

UNIT HYDROGRAPH AND DETERMINATION OF DESIGN FLOOD

Flash flood in Zarqa Ma'in was occurred with precipitation did not exceed 43 mm with a duration of 22 minutes. Therefore, it is necessary to estimate the expected flood discharges of return periods reliably for future developments and protection. There are no stations of stream flow measurement located in Zarqa Ma'in catchment area. Therefore, to estimate the runoff, the US Soil conservation services method (SCS), (**Wanielista, 1990**), was applied to compute the runoff occurred from various storms of normal conditions. This method takes the initial abstraction of rainfall and the land use, the antecedent moisture conditions (AMC). The maximum retention and the watershed characteristics are related throws the curve number (CN). By using the WMS 11 software the CN was calculated by the calculator's extension based on the LU/LC relation. The curve number for the study area is 92.

The SCS runoff Equation (1) was used for runoff depth calculation.

$$Q = \frac{(p-0.2S)^2}{(p+0.8S)} \quad (1)$$

Where

Q = The runoff depth (mm)

P = The precipitation depth (mm)

S =The total losses of the rainfall depending on soil type (mm) and it can be determined by the following equation:

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Initial abstraction (Ia) is the overall losses of the rainfall before runoff starts. Ia is highly variable but generally is related to soil parameters.

$$Ia = 0.2S \quad (3)$$

Where:

Ia= Initial abstraction (mm)

By using the SCS runoff equation, daily runoff volume was calculated, and the yearly amounts were accumulated. The average annual rainfall in Ma'in station ranges from 450 mm to 23 mm and the mean annual runoff ranges from 361 mm to 5.5 mm (Figure 16). The mean annual runoff is equal 167.4 mm/year (Figure 16). The annual runo percentage ranged between 23.9 and 85.5% of annual rainfall (Figure 16).

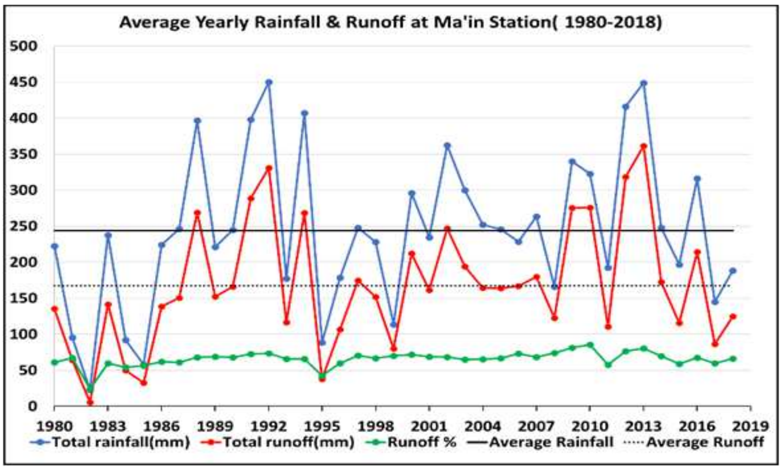

Figure 16: Yearly Rainfall and Runoff and Percentage Runo of Ma'in Station.

The runoff hydrograph ordinates depending on the rainfall depth of the desired return periods were estimated from the unit hydrographs. The storm hydrograph peak flows obtained for the basin are presented in Table 5. The runoff hydrograph for the peak discharges of different return periods for each time is displayed in Figure 17. The calculated flood volumes are presented in Table 6 as Million Cubic Meter (MCM) for the 2,5, 10, 25, 50, 100, and 1000 year return period

Table 5: Peak Runoff for Zarqa Ma'in Basin (m^3/s)

Time	Storm return periods and peak flows (m^3/s)						
	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	1000 Years
5 min	1.51	8.19	15.27	26.66	36.57	47.35	88.47
10 min	4.67	17.41	29.24	47.09	62	77.94	135.82
30 min	14.83	40.73	62.21	92.75	117	142.32	230.6
1 hr	32.01	74.84	107.94	153.08	188.15	223.9	347.31
3 hr	73.57	148.54	202.69	274.36	329	383.93	568.37
6 hr	115.23	216.99	289.05	382.61	453.09	523.51	757.9
12 hr	172.28	307.99	401.67	521.87	611.69	701.16	997.05
24 hr	248.72	426.04	546.18	699.03	812.74	925.59	1297.66

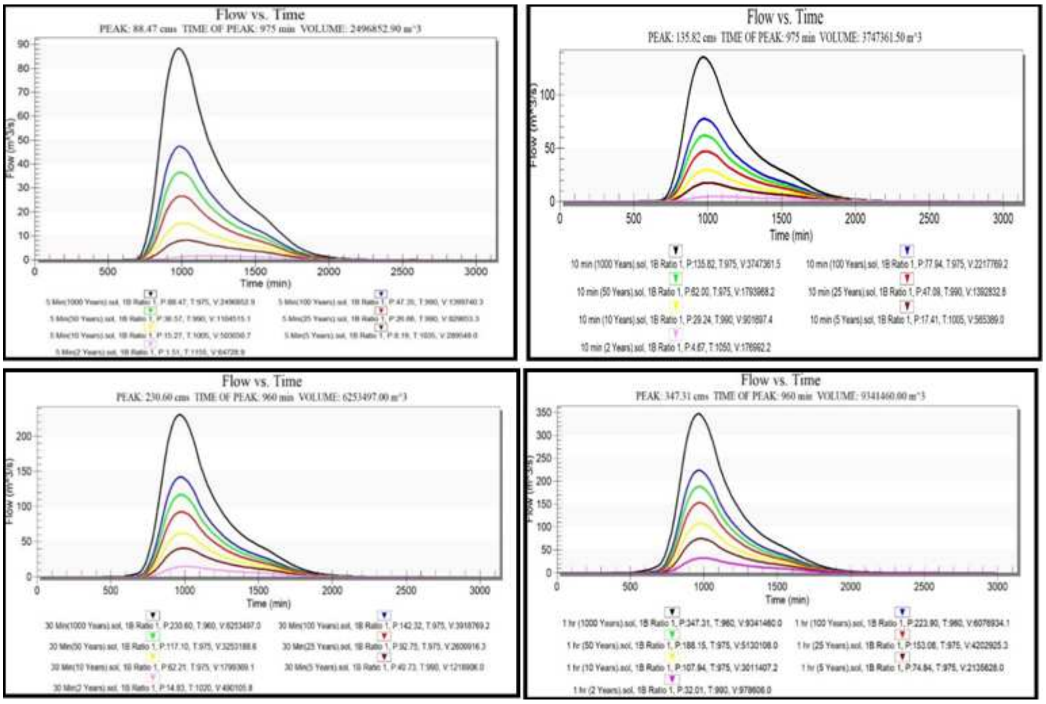

Figure 17: The 5, 10, 30 and 60-Minute Hydrograph of the Different Return Periods for Zarqa Ma'in Catchment.

Table 6: The Flood Volumes of Zarqa Ma'in Basin (MCM)

Time	Storm Return Periods and Peak Flows						
	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years	1000 Years
5 min	0.13	0.71	1.32	2.30	3.16	4.09	7.64
10 min	0.40	1.50	2.53	4.07	5.36	6.73	11.73
30 min	1.28	3.52	5.37	8.01	10.11	12.30	19.92
1 hr	2.77	6.47	9.33	13.23	16.26	19.34	30.01
3 hr	6.36	12.83	17.51	23.70	28.43	33.17	49.11
6 hr	9.96	18.75	24.97	33.06	39.15	45.23	65.48
12 hr	14.88	26.61	34.70	45.09	52.85	60.58	86.15
24 hr	21.49	36.81	47.19	60.40	70.22	79.97	112.12

To determine how the runoff is distributed over time, we must introduce a time-dependent factor. The time-of-concentration (Tc) is utilized for SCS methods. Tc is most often defined as the time required for a particle of water to travel from the most hydrologically remote point in the watershed to the point of collection. The time concentration, (Tc) is defined as the time required for the most remote drop of water to reach the outlet of the catchment. To estimate peak discharge, the morphometric parameters were determined dependent on the available Drainage Elevation Map (DEM); which include drainage area (A), the length of the longest main stream (L), the elevation difference (H) between the highest point of the mainstream and the outlet of the wadis, and the average slope (%) (Table 7).

Table 7: Hydrologic Characteristics of the Zarqa Ma'in Catchment Area

Catchment Parameters	Unit	Value
Hydraulic Length (L)	(Km)	55
Hydraulic Length (L) (Mile)	(mile)	34.17
Elevation difference (H)	m	1318
Average Slope	%	2.40
Drainage Area (A)	(Km^2)	276
Drainage Area (A)	($mile^2$)	106.56

The design duration is equal to the time of concentration for the drainage area. In literature, there are a number of equations and methods to estimate the time of concentration with different boundary conditions. The most applicable eight equations representing different watersheds were used to estimate the time of concentration and the minimum was considered. There are several methods available for calculating tc, one of which is the Lag Method:

$$t_c = \frac{100(3.281L)^{0.8}\left[1000/CN-9\right]^{0.7}}{1900(100S)^{0.5}} \tag{4}$$

Where:

tc = Time of concentration, in min.

L = Length of longest watercourse, in m. S = Slope of flow path, in m/m.

CN = SCS runoff curve number, according to land use, hydrologic soil group, and moisture condition, weighted value is calculated.

The second equation that can be used to estimate tc is the Kirpich formula (Kirpich, 1940); which can be used mainly for small watersheds:

$$t_c = 0.0078(3.281L)^{0.77} S^{-0385} \tag{5}$$

The potential maximum retention of soil can be obtained from the following equation:

$$\mathbf{S = \frac{1000}{CN} - 10} \tag{6}$$

Where

S: potential maximum retention (inch) CN: Curve number.

In order to use this method, the time to peak and the peak discharge are estimated. The method assumes that: The duration of excess rainfall is less or equal D = 0.133 x the time of concentration, and that,

The rainfall duration is not too long (D<0.2 time to peak).

The time of concentration can be calculated using lag time as follows:

Tc = 1.67 *t1 (7)

Where

Tc: time of concentration (Hours) T1: lag time (hours)

The Time of peak (Tp) was calculated by:

$$\mathbf{Tp = \frac{D}{2} + 0.6 * Tc} \tag{8}$$

Where

Tp: time of peak (Hours) D: duration equal 1 hour.

Peak discharge can be calculated by:

$$Q_P = \frac{2.08 * A}{T_P} \qquad (9)$$

Where

Qp: peak discharge of the unit hydrograph (m^3/s) 2.08: constant value

A: area (Km^2).

T_p is the time to peak in (hr)

According to the hydrological parameters of the sub-catchments, the calculated lag time (tl), time of concentration (tc), time to peak (Tp) and the peak discharge (Qp) for Zarqa Ma'in catchment is summarized in Table (8). The peak discharge in the outlet is around 64.028 m^3/s and a total discharge volume of 2.019 MCM/Year as shown in Table 8. On the other hand, the Unit Hydrograph for Zarqa Ma'in catchment is shown in Figure 20

Table 8: Hydrological Parameters of the Zarqa Ma'in Catchment by using SCS Method

Area (Km^2)	Longest Path (Km)	CN	S	Lag time (Tl) (hr)	tc SCS (min)	Tp (h)	Basin Slope (%)	Qp (m^3/s)
276	55	92	23.426	8.45	14.11	8.97	2.37	64.03

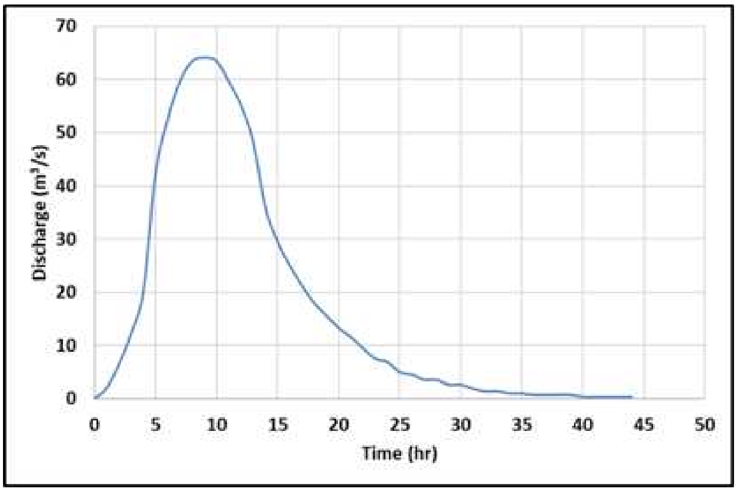

Figure 18: Unit Hydrograph for Zarqa Ma'in Catchment Area.

FLASH FLOOD ON OCTOBER 25TH, 2018 IN ZARQA MA'IN AREA

The rainfall amounts on October 25th, 2018 where collected from the MWI data base and the Jordan Meteorological Department for all rainfall gauge stations that are disseminated in and encompassing the investigation the flooded area. Rainfall amounts are present in Table 9.

Table 9: Rainfall Amounts for Rainfall Gauge Stations

Station ID	Station Name	Gage Weights	Precipitation (mm)
CC0002	MA'IN	0.37	43
CC0001	MADABA	0.28	27
CD0028	MULEIH	0.035	18
CC0004	MUSHAQQAR EVAP. ST	0.12	30
CD0016	JUDAYDA	0.18	15

The WMS package has been used to simulate the October 25th 2018 event. Losses in each sub-basin were calculated using the SCS-curve number and the SCS dimensionless hydrograph was used to transform the excess rainfall into runoff. Figure 19 and 20 show that the estimated runoff water volume at the wadi outlet using WMS approach while accounting. The flood hydrographs and peak flows were determined for both sub-basin (Figure 19, 20). Results indicate that the flood hydrograph volume is about 2.98 MCM with a peak discharge of about 102.94 m^3/s for sub-basin 1, and 1.31 MCM with a peak discharge of about 126.66 m^3/s for sub-basin 2. The hydrographs and peak flows were determined for sub-basin 1 and sub-basin 2 and illustrated in Figure 21. Table 10 shows the hydrological parameters of the two sub-basin and the outlet from the catchment.

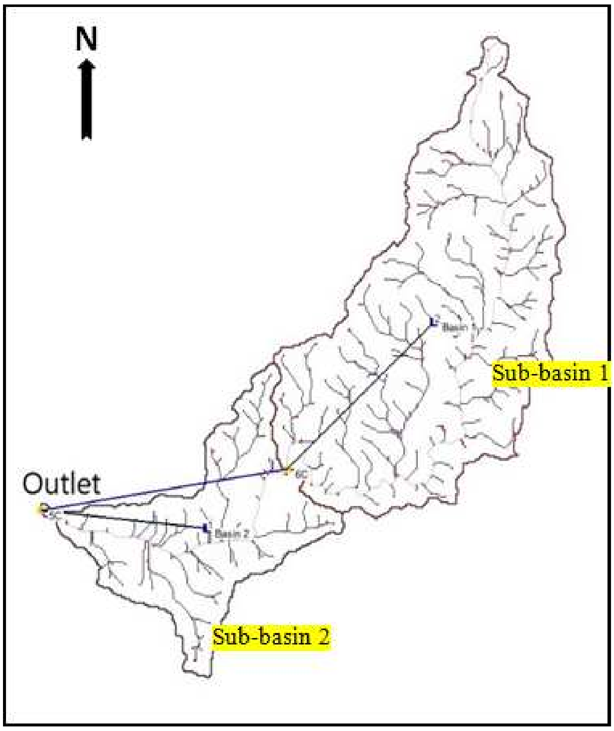

Figure 19: Schematic Simulation of the Zarqa Ma'in Catchment Area.

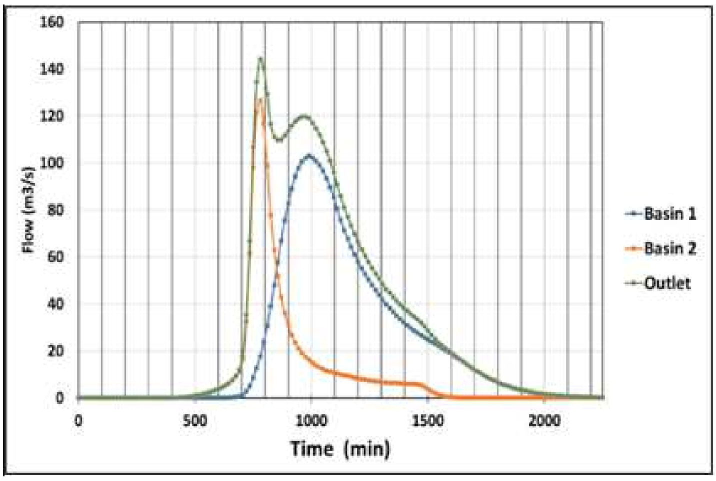

Figure 20: Peak Flow Discharge Hydrograph Created by WMS (11.0) for the Two Sub-Basins and at the Outlet.

Table 10: Hydrological Parameters of the Zarqa Ma'in Catchment by using SCS Method

Basin	Area (Km^2)	Longest path (Km)	CN	S	Lag time (Tl) (hr)	tc SCS (min)	Tp (h)	Basin Slope (%)	Qp (m^3/s)	Volume MCM
Sub-basin1	194.8	24.1	91	24.8	4.13	6.9	4.6	6.2	102.9	2.98
Sub-basin2	81.2	10.8	96	10.3	1.04	1.7	1.5	23.3	126.7	1.3
Outlet	276	34.9	92	23.43	5.2	8.6	6.1	6.32	146.7	4.3

HYDRAULIC MODELING RESULTS

HEC-RAS model development was a distinguished model to be utilized for the computations of the water level of the precursor floods in the chose aqueduct courses. A cross-section of the sub-basin 1 and sub-basin 2 was taken. The peak discharge value was 102.94 m^3/s in sub-basin 1 and 126.66 m^3/s for sub-basin 2. **Figure 21** shows the cross section and the water surface profiles that the model predicted for sub-basin 1. Results indicates the water surface level reached 423 meters and the water height in the cross-section1 from the ground to the surface was11 meters. On the other hand, Figure 22 shows the water surface profiles that the model predicted for sub-basin 2 and the water surface level reached -220.91 m and the water height in the cross-section from the ground to the surface was 3 m.

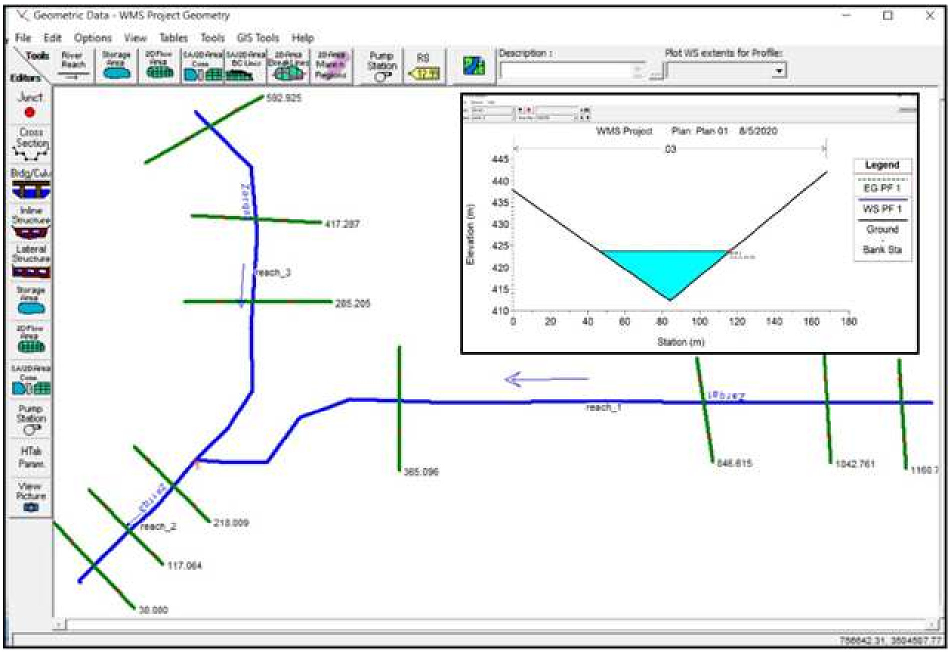

Figure 21: Cross Section and Water Surface Profile on River Stream in Sub-Basin 1.

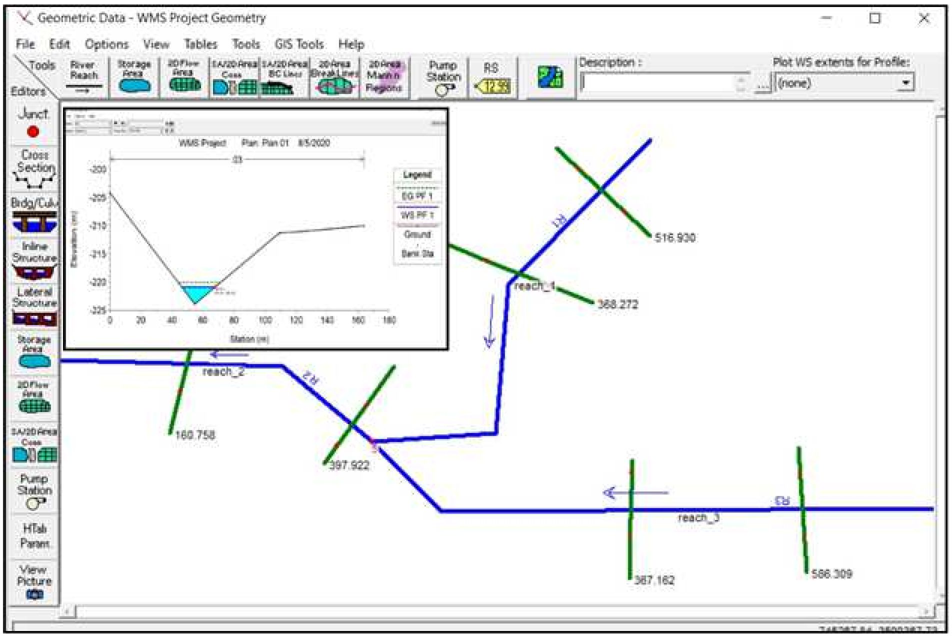

Figure 22: Cross Section and Water Surface Profile on River Stream in Sub-Basin 2.

RESULT AND DISCUSSION

From the climatic data analysis and its findings, it is clear that there is an increase in rainfall amounts associated by a rise in temperature, and a decrease in relative humidity over time. This could be attributed to climate change. Moreover, when air temperature increases, air can hold more water molecules, and its relative humidity decreases. However, in the arid areas during the nights and during temperature drops, relative humidity increases which will increase the chance for precipitation (Lawrence, 2005). Climate change leads to flash floods. This is due to several factors, including heavier precipitation. In the future, heavy precipitation events are projected to increase (along with temperatures) because of climate change. This includes extreme weather events known as atmospheric rivers which are air currents heavy with water from the tropics (IPCC, 2017). As the IPCC concluded in its special report on extreme events. There is more data on rainfall that exists, and some evidence for a trend towards heavier rainfall. This is due to greenhouse gas emissions contributing to observations of more intense precipitation. Modeling results show that the annual mean temperature in the study area is likely to increase in addition to shifting in the hydrological year. In Jordan, the hydrologic year starts on September 15th and lasts until June in the following year. In the last few decades, winter has followed this regime, however in the last 10 years there has been a shift in the rainy months, which lead to rain beginning in December and heavy rain beginning in January. Thus, this leads to increased annual average precipitation and an increased amount of evaporation which will increase the chance for more precipitation and occasional flash floods and frequency of extreme weather events. The land used in the study area is widely variable due to its natural characteristics. The bare rocks and bare soil cover about 35% of the Zarqa Ma'in catchment area, moreover, this percent represent more than 85% from sub-basin 2. This nature of LU/LU will be causing an increase in the velocity of runoff water and accelerate its flood peak; in addition, the texture of soil samples is sandy loam and clayey sandy loam which has a great influence on the runoff volume. This soil is characterized by its capability of quickly draining excess water which contributed to the increase in water runoff and flash flood, toward the Dead Sea. The catchment area of Zarqa Ma'in was divided into two sub-basins, the area of these sub-basins is 81 to 195 Km^2 for sub-basin 1 and sub-basin 2 respectively, and their longest flow paths range from 39.3 to 21.4 Km, respectively. Analysis of morphometric parameters showed that the morphometric characteristics of the watershed contribute in high-speed floods with low infiltration rates. The total runoff computed by the model was found to be 146.7 m^3/s or 4.3 MCM. During the disaster event which occurred on October 25th, 2018, the intensity of the rainfall, which reached 43 mm in Ma'in area in 22 minutes in an area not more than 81 Km^2 draining to Zarqa-Ma'in Valley. The intensity of the rainfall was not expected and was extreme; it occurred mostly on bare rocks with steep slopes without any infiltration or water absorption. This huge amount of water ran in the Zarqa Ma'in Wadi, which is characterized by steep narrow banks leading to a rise in the water level to about 11m and at least 3m in height of water drained into the Dead Sea. This resulted in a huge flood, and consequently a mudflow containing boulders and gravel towards the Dead Sea. According to the IDF curves for Ma'in rainfall gauge station, the amount of this thunderstorm is almost similar to the maximum storm events that occurred for a return period of 2, 10, 25 and 1000 years during 10, 20, 30, and 60 minutes respectively. The hydrological parameters of the two sub-basins, the lag time (t_l), time of concentration (t_c), time to peak (T_p), and the peak discharge (Q_p) for Zarqa Ma'in catchment have been calculated, with T_c being around 2 minutes, T_p was 1.5h, and the peak discharge (Q_p) in the outlet point next to the Dead Sea was around 146.7 m^3/s.

CONCLUSIONS

This research presents an analysis method to calculate the flood water discharged from the Zarqa Ma'in Catchment area by using the available data set from both MWI and Meteorology Department. Meteorological data like temperature and relative humidity indicates that there was an increase in precipitation and a decrease in relative humidity and a rise in temperature over the year which is due to climate change. This leads to changing weather patterns and the occurrence of strong rainy depressions at an untimely date of the year and thus leads to flash floods that have a significant impact on the environment and people. This is what happened in the Dead Sea region. In this study area, a flash flood occurred due to the occurrence of a severe thunderstorm in a short period on the mountain slopes, which were mostly covered by weeds scattered, in the Zarqa Ma'in area. The study area is characterized by moderate to relatively steep slopes, this resulted in high-speed runoff generation due to the inability of the catchment to obstruct the flow. The rainfall event of Zarqa Ma'in on October 25th, 2018 was simulated on catchment using the generated unit hydrograph. Flood hydrographs have been created at the outlet of the sub-basins catchment area in addition to at the catchment outlet. Flood hydrographs were derived for the two sub-catchments of the whole Zarqa Ma'in catchment. Results indicate that the flood hydrograph volume is about 2.98 MCM with a peak discharge of about 102.94 m^3/s for sub-basin 1, and 1.31 MCM with a peak discharge of about 126.66 m^3/s for sub- basin 2. HEC-RAS Model Development was a recognized model utilized for the calculations of the water level of the antecedent floods for computing the flood wave propagation resulting from a thunderstorm scenario. The peak discharge data for each catchment calculated with HEC-HMS are used as an input to the HEC-RAS to model the water depths and along the flood path. In HEC-RAS, the flood path is defined through 16 cross-sections extracted from the TIN of the study area. The water depth ranges between 11m in Wadi Zarqa Ma'in to 3m at the outlet of the catchment area. Information on the flash floods on October 25th, 2018 may be used as a realistic scenario of future similar events. Clearly, many lessons can be learned from this catastrophic event in order to reduce potential damage, and create an early warning system in the area. It is necessary to provide some prevention such as installing water infiltration bonds and a water retention system to increase the infiltration and decrease the speed of the flood water. Moreover, all catchment areas that are subjected to flash floods must also be subjected to flood hazard assessment.

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REFERENCES

1. *Abdulla, F. 2020. 21st Century Climate Change Projections of Precipitation and Temperature in Jordan. 1st International Conference on Optimization-Driven Architectural Design (OPTARCH 2019). Proced. Manuf., 44, 197- 204.*
2. *Al-Sharaan, M. 2018. Jordan floods. Why is the scene of death repeated? Aljazeera. News, Reports and interviews, Amman. Retrieved from: h ttps://www.aljazeera.net/news/reportsandinterviews.*
3. *Al-Weshah, R., and El-Khoury, F. 1999. Flood Analysis and Mitigation for Petra Area in Jordan: Journal of Water Resources Planning and Management, 125(3), 170-177.*
4. *Bender, F. 1974. Geologie von Jordanien, Beitra¨ge zur Reg. Geol. der Erde, 7.*
5. *Farhan, Y., and Anabr, A. 2016. Flash Flood Risk Estimation of Wadi Yutum (Southern Jordan) Watershed Using GIS Based Morphometric Analysis and Remote Sensing Techniques: Open Journal of Modern Hydrology, 6, 79-100.*
6. *Farhan, Y. and Ayed, A. 2017. Assessment of Flash-Flood Hazard in Arid Watersheds of Jordan. Journal of Geographic Information System, 9, 717-751.*
7. *Hunting Technical Services, Soil Survey and Land Research Centre (HTS and SSLRC) 1993. The Soils of Jordan. Ministry of Agriculture, National Soil Map and Land Use Project, Level 1: Reconnaissance Soil Survey (Scale 1: 250,000), 3 Volumes, Amman.*
8. *IPCC 2017. Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Mitigation, Sustainability and Climate Stabilization Scenarios. [Shukla, P.R., J. Skea, R. Diemen, E. Huntley, M. Pathak, J. Portugal Pereira, J. Scull, and R. Slade (eds.)]. IPCC Working Group III Technical Support Unit, Imperial College London, London, UK, 44 pp.*
9. *Keliler, M. Knight, J. Harrison, S. 2010. Climate change and geomorphological hazards in the eastern European Alps Philosophical Transactions of the royal society 368, 2461-2479.*
10. *Khouri, H., Salameh, E. and Udluft, P. 1984. On the Zarqa Main (Thermal Kallirhoes) Travertine/Dead Sea. N Jb Geol Paleontl Mh H 8, 472-484.*
11. *Kirpich, Z.P., 1940. Time of concentration of small agricultural watersheds. Civ. Eng. 10 (6), 362.*
12. *Lababneh, A. Al Kuisi, M. and Al-Bilbisi, H. 2019., Hydrological modeling for Al Hasa catchment area using GIS Technique. Journal of Engineering Research and Application Vol. 9, Issue 2 (Series -I), 38-48*

13. *Lawrence, Mark G., 2005. The Relationship between Relative Humidity and the Dew point Temperature in Moist Air: A Simple Conversion and Applications. Bull. Amer. Meteor. Soc., 86, 225-233.*

14. *Margane, A. Hobler, M., Almomani, M. and Subah, A. 2002. Contributions to the hydrogeology of Northern and Central Jordan. E. Schweizerbart Science Publishers, Stuttgart.*

15. *Myronidis, D. Papageorgiou, C. Theoplanous, S. 2016. Landslide susceptibility mapping based on landslide history and analytic hierarchy process (AHP) Nat. Hazards, 81, 245-263.*

16. *Namrouqa, H. 2018, October 26. Death toll rises to 21 in Dead Sea flash floods. The Jordan times Retrieved from: http://www.jordantimes.com/news/local/death-toll-rises-21-dead-sea-flash-floods*

17. *Odeh, T. Geyer, S. Rödiger, T. Siebert, C. and Schirmer, M. 2013. Groundwater chemistry of strike slip faulted aquifers: the case study of Wadi Zerka Ma'in aquifers, north east of the Dead Sea. Environ Earth Sci 70, 393–406.*

18. *Sawarieh, A. and Massarweh, R. .1995. Geothermal water in Zara and Zarqa Ma'in area. NRA, Amman, report 8, 36.*

19. *Shawabekeh K 1998. The geology of Ma'in area map sheet No. 3153 (III), The Jordanian Natural Resources Authority Publication 40.*

20. *Peel, MC. Finlayson, BL. McMahon, T. 2007. Updated world map of the K€oppen_Geiger climate classification. Hydrology Earth Syst Sci. 11,1633-1644.*

21. *Wanielista, M. 1990. Hydrology and water quantity control, John Wiley and Sons Inc., USA.*

22. *Youssef, A. Sefrya, S. Pradhanc, B. Abu Alfadaila, E 2015. Analysis on causes of flash flood in Jeddah city (Kingdom of Saudi Arabia) of 2009 and 2011 using multi-sensor remote sensing data and GIS. Geomatics, Natural Hazards and Risk,1,1-25.*

23. *Svetlana,D. Radovan, D. Ján, D. 2015. The Economic impact of floods and their importance in different Regions of the World with Emphasis on Europe. Procedia Economics and Finance, 34, 649 - 655.*

24. *Zeineh, A. 2018. Flash Floods .Retrieved from: https://alghad.com/%D9%81%D9%8A%D8%B6%D8%A7%D9%86%D8%A7%D8%AA-%D8%AE%D8%A7%D8%B7%D9%81%D8%A9/*